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## ANTIBODIES ANTI-C5 COMPONENT OF THE COMPLEMENT SYSTEM AND THEIR USE

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### Description

#### FIELD OF THE INVENTION AND BACKGROUND OF THE ART

- [0001]        Activation of the complement system (C system) represents an important mechanism in the immune defence. At the same time it represents a double-edged weapon because on the one hand guarantees protection of the host but on the other is capable of damaging tissues where complement is activated by several pathological circumstances. The increased susceptibility to bacterial infections and autoimmune disorders observed in patients with inherited deficiencies of the C system clearly demonstrates the particular importance of this system in host protection against infectious agents and in the clearance of immunocomplexes.
- [0002]        These protective functions result from complement activation in cascade fashion that generates biologically active products. Some of those, such as C1q, C3b and C3bi, opsonize the infectious agents enabling their disposal. Instead others, such as C5a and C5b67, have the function to recruit phagocytic cells at the site of inflammation or lyse sensitive targets as in the case of the membrane attack complex (MAC). Unfortunately, these molecules, once they are produced, are not able to discriminate between endogenous and exogenous targets, and would provoke serious damage to tissues and cells if those were not protected by potent membrane or extracellular inhibitors acting at various levels in the complement activation cascade. However, the action of inhibitors is overwhelmed in presence of a massive activation of the C system, in serious infectious diseases or autoimmune disorders, and the activated complement causes tissue and cell destruction.
- [0003]        The C5a fragment and the C terminal complex (TCC) are among the products involved in tissue destruction in several inflammatory processes. Above normal levels of these activation products can be found in synovial fluid of rheumatoid arthritis patients and in cerebrospinal fluid of patients with several diseases of the central nervous system.

Elevated C5a levels have been found also in polytraumatized patients as well as in patients with damage from myocardial ischemia and re-perfusion.

[0004] Therefore the role of C5a in development of these diseases is now recognized.

[0005] This is demonstrated by the signs of pulmonary stress, hypotension and leukopenia shown by animals that have received intravenous injection of this anaphylatoxin. Moreover bronchial instillation of C5a is capable of inducing strong inflammatory reactions in rabbit lung.

[0006] TCC is generated from the C5b fragment released by enzymatic cleavage of C5 by the action of C5 convertase. Recently it has been demonstrated that TCC induces inflammation because of tissue damage deriving from its lytic activity and of numerous non-cytotoxic effects on phagocytes and other cell types.

[0007] TCC has been identified in several tissues in diverse pathological conditions, including rheumatoid arthritis, glomerulopathies multiple sclerosis, demyelinating peripheral neuropathies, atherosclerosis and myocardial infarction. The development of experimental animal models of these diseases with selective deficiencies in late C components has further contributed to define the role of these components in development of tissue damage.

[0008] Because of the fundamental role played by C5a and TCC in promoting chronic inflammation and tissue damage, several attempts have been made to neutralise the late components of the C complex as therapeutic strategy to prevent these complications in diseases associated with C5 activation. This molecule turns out to be an ideal therapeutic target, since its neutralisation inhibits the late sequence of activation events of the cascade, without interfering with the opsonizing activity of the early components of this cascade. Mouse monoclonal antibodies specific for human, mouse and rat C5 and capable of inhibiting the production of C5a and of the membrane attack complex (MAC) are already commercially available. Anti-C5 antibodies have been successfully used in mice to prevent the development of collagen-induced arthritis and to improve the clinical course of glomerulonephritis, and in rats to reduce myocardial ischemia and re-perfusion.

[0009] In the last years two single chain antibodies (single chain antibody or single chain fragment variable, scFv) have been produced that are both described in patent application WO 95/29697. These antibodies are able to penetrate tissues more rapidly than the whole antibody. The first single chain antibody obtained by assembling variable regions of a mouse antibody for C5 retains the ability of the original antibody to inhibit assembly of

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the MAC and partially block C5a production (Evans, M. J *et al.*, 1995, Mol. Immunol. 32:1183). Moreover, this antibody is able to prevent C5b-9 deposits in the heart re-perfused with human plasma or in heart insufficiency. The second scFv is a humanised mouse antibody anti-C5, that is obtained by inserting murine CDR regions (complementarity determining region) in the structure of the variable region of human light and heavy chains. This antibody (Thomas, T. C. *et al.*, 1996, Mol. Immunol. 33:1389) is able to inhibit C5a and C5b-9 formation although the recognised epitope mapped around amino acids 860-865 of the C5 molecule and corresponding to peptide KSSKC (SEQ ID NO: 36), turns out to be far from the C5 convertase cleavage site. Moreover subsequent studies (Fitch, J. C. *et al.*, 1999, Circulation 100:2499) have demonstrated that this antibody is able to inhibit complement hemolytic activity, to attenuate myocardial damage, cognitive damage and postoperative haemorrhage in a group of patients with cardiopulmonary bypass.

## SUMMARY

[0010] The main aspect of the invention refers to an antibody of human origin specific for the C5 component of activated complement and characterised by the fact that it inhibits cleavage of the C5 alpha chain into C5a and C5b. In particular, the antibody is recombinant and recognises an epitope comprising the proteolytic site for the C5 convertase on the alpha chain of the C5 complement component.

[0011] According to a preferred embodiment, the recombinant antibody is composed of a single chain (scFv) comprising a variable region of the light chain covalently bound to a variable region of the heavy chain and, according to an even more preferred aspect is composed of or comprises at least one of amino acid sequences selected among SEQ ID NO[[ ]]: 2, 4, 6 or proteins having at least 95% homology to such polypeptides.

[0012] In accordance with a further aspect, the invention includes the isolated nucleotide sequences encoding antibodies specific for C5 component of activated complement. These antibodies are characterised by the fact that they inhibit cleavage of the C5 alpha chain into C5a and C5b, and in particular the sequences chosen between: SEQ ID NO: 1 or 3 or 5 and the vectors containing these sequences. In accordance with a further aspect, the invention refers to the therapeutic use of antibodies and nucleotide sequences for preparation of drugs that prevent and treat diseases involving uncontrolled activation of

the complement system, in particular: rheumatoid, arthritis, glomerulonephritis, multiple sclerosis, demyelinating peripheral neuropathies, atherosclerosis.

## DESCRIPTION OF THE FIGURES

[0013] Figure 1. Assessment of the ability of anti-C5 clones scFv Ts-a12 and Ts-a12/22 to inhibit formation of C5a fragment by means of an ELISA assay (panel A) and an haemolytic assay (panel B).

[0014] Panel A) The ELISA assay measures the amount of C5a fragment released in the supernatant after enzymatic cleavage of C5, using antibodies anti-C5 as described in example 6. Incubation of C5 with antibodies Ts-a12 and Ts-a12/22 of the invention inhibits formation of the C5a fragment. Sheep erythrocytes sensitised with antibodies and coated until the C3b (EAC1-3b) ~~complement~~ complement step were added to the mixture of TS-A12 or TS-A12/22 and C5, and the mixture was further incubated for 30 minutes at 37°C. (panel B). As shown in Figure 1 A and B, TS-A12 and TS-A12/22 antibodies inhibit C5 cleavage by C5 convertase and therefore inhibit formation of C5a (Panel A) and of TCC (Panel B).

[0015] Symbols: -▲-: Ts-A12/22; -■-: unrelated scFv; -◇-: TS-A12.

[0016] Figure 2. Immunoblotting to identify the C5 chain recognised by scFv TSA-12/22.

[0017] The alpha and beta chains of C5 were electrophoretically separated by means of SDS-PAGE in 10% polyacrylamide and then transferred onto nitrocellulose. The immunoblot (lanes 1 and 2) was developed with TSA-12/22 antibody and revealed by incubation with anti-SV5 (SV5 tag) monoclonal antibody followed by incubation with a goat anti-mouse IgG antibody labeled with alkaline phosphatase. Lane 1: 100 ng of C5 alpha chain; lane 2: 100 ng of beta chain; lane 3: mixture of the two chains. Immunoblot in lane 3, used as positive control, was developed with a biotin conjugated goat anti-human C5 antibody that recognises both alpha and beta chains and was revealed with alkaline phosphatase labeled avidin. It can be seen that scFv TSA-12/22 recognises the alpha chain of C5 in lane 1, but not the beta chain in lane 2.

[0018] Figure 3. Inhibition of the binding of C5 and scFv of the invention by peptide P5A-18 (KDMQLGRLHMKTLTPVSK) (SEQ ID NO:15) comprising the C5 convertase cleavage site.

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- [0019] Mixtures of scFv TSA-12/22 (1 µg/ml) containing 200, 400 and 800 ng of P5A-18 peptide, with sequence KDMQLGRLHMKTLLPVSK [SEQ ID NO:15], comprising the C5 convertase cleavage site, or 800 ng of unrelated peptide CS5, derived from fibronectin (GEEIQIGHIPREDVDYHLYP SEQ ID No. 16 of sequence listing) or 3.5 µg of C5a fragment or saline solution (control) were incubated as described in example 8. Binding of the antibody, pre-incubated in different conditions, was assessed by immuno-enzymatic assay using C5 on solid phase. Inhibition by the P5A-18 peptide of the binding between scFv of the invention and C5 is dose-dependent, ranging between 45% to 90% for peptide concentrations of 200 and 800 ng, respectively. These values correspond to a  $K_i$  of 1 µM for the P5A-18 peptide. No inhibition is observed using C5A or the unrelated peptide.
- [0020] Figure 4. Inhibition of hemolytic activity of C5 by the TS-A12/22 antibody.
- [0021] Values from spectrophotometric reading performed at 412 nm to measure inhibition of lysis of sheep erythrocytes coated with EAC1-3b, through the classical complement activation pathway (A Panel); or of rabbit erythrocytes in order to measure the alternative pathway of complement activation (B Panel). Increasing amounts of C5 were mixed with 600 ng of the scFv antibody of the invention with an unrelated scFv, or with GVBS in which the scFv of the invention were solubilised, as described in example 9. After incubation with serum lacking in C5, obtained from a patient with selective deficiency of this complement component, the percentage of hemolysis was measured compared to the 100% value obtained by lysing erythrocytes in an equal volume of distilled H<sub>2</sub>O and a blank obtained by resuspending erythrocytes in GBVS.
- [0022] Symbols: -◇-: TS-A12/22; -■-: unrelated scFv; -▲-: GVBS.
- [0023] Figure 5. Inhibition of C5 hemolytic activity in mammalian serum by the TS-A12/22 antibody.
- [0024] Measurements were performed as described in example 8, using sera from human (panel A), rat (panel B), rabbit (panel C), mouse (panel D).
- [0025] Symbols: -▲-: GVBS TS-A12/22; -■-: unrelated scFv; -◇-: TS-A12/22.
- [0026] Figure 6. Inhibition of intra-articular migration of Polymorphonuclear Leukocytes (PMN) by the TS-A12/22 antibody in rat models of antigen-induced arthritis.
- [0027] Polymorphonuclear Leukocytes (PMN), isolated from intra-articular wash out of rats with arthritis induced by instillation of BSA (mBSA), were incubated with antibody

- TS-A12/22 or with an unrelated antibody, as described in example 10. The number of PMN in the joint treated with the antibody of the invention appears drastically reduced.
- [0028] Saline solution: control without induced arthritis; mBSA: BSA-induced arthritis, untreated; unrelated: BSA-induced arthritis, treated with unrelated scFv antibody; Ts-a12/22: BSA-induced arthritis, treated with the antibody of the invention.
- [0029] Figure 7. Immunofluorescence analysis of synovial membrane from rats with antigen-induced arthritis.
- [0030] Histological sections of joints from rats treated with intra-articular injection of saline (A), BSA (B), BSA with TS-A12/22 (C) and BSA with the unrelated antibody (D) were analysed by immunofluorescence for the presence of complement components C3 and C9, as described in example 10. It is emphasised that the treatment with TS-A12/22 does not affect the deposition of C3 but significantly reduces that of C9, thus confirming the inhibition of C5.
- [0031] Figure 8. Schematic representation of *minibodies* prepared from ScFv sequences including human, mouse and rat constant regions.
- [0032] Figure 9. Inhibition of the classical complement activation pathway.
- [0033] Symbols: -▲-: GVBS; -■-: unrelated scFv; -◇-: TS-A12/22-CH2CH3 (*minibody*); -■-TS-A12/22 (scFv).
- [0034] Figure 10. Inhibition of intra-articular migration of Polymorphonuclear Leukocytes (PMN) by the TS-A12/22-CH2CH3 antibody (*minibody*) in rat models of antigen-induced arthritis.
- [0035] From left: bar 1: control (mBSA); bar 2: mBSA + TS-A12/22-CH2CH3 (*minibody*) injected at time 0; bar 3: mBSA + TS-A12/22-CH2CH3 (*minibody*) injected at 6 hours from induction of arthritis.
- [0036] Figure 11. Reduction of the joint swelling.
- [0037] The antibody, under the form of minibody, was injected in the model of mBSA-induced arthritis in rat at time 0 and 6 days after BSA treatment. Percentage values on the ordinate have been obtained with respect to the basal diameter of the joint prior to induction of arthritis. Days are indicated on the abscissa.
- [0038] From left: bar 1: control (mBSA); bar 2: mBSA + TS-A12/22-CH2CH3 (*minibody*) injected at time 0 from induction of arthritis; bar 3: mBSA + TS-A12/22-CH2CH3 (*minibody*) injected at 6 hours from induction of arthritis.

## DETAILED DESCRIPTION OF THE INVENTION

[0039] The main object of the present invention relates to an antibody of human origin which has specificity for the C5 component of the complement system and is characterised by the fact of inhibiting the cleavage of C5 alpha chain, also termed activated C5, into C5a and C5b fragments. This cleavage occurs as result of complement activation occurring by known mechanisms.

[0040] Following Complement activation, a C5 convertase is produced which cleaves the alpha chain of factor C5 generating a fragment of approximately 70 amino acids (aa), known as C5a, and a C-terminal fragment of 925 aa, C5b. The products resulting from C5 activation, C5a and C5b, are biologically active. In particular, C5a has chemotactic activity toward polymorphonuclear leukocytes and monocytes, whereas the C5b fragment contributes to formation of the terminal complement complex (TCC).

[0041] The antibody is preferably recombinant.

[0042] The antibody of the invention is of human origin, i.e. it is entirely derived from an antibody repertoire obtained from human lymphocytes. These antibodies have both framework and antigen complementary regions (CDR) of human origin, unlike humanised antibodies where only the framework is of human origin, while the CDR are of murine origin.

[0043] Herein, by recombinant antibody it is meant an antibody composed of at least one variable region derived from the heavy or light chain of an immunoglobulin and produced by means of genetic engineering techniques from the nucleotide sequences coding the characterising regions of the antibody. The recombinant antibody is produced in a host organism which is usually a bacteria, a yeast, or a higher eukaryotic cell (of plant or animal origin). The technique of genetic engineering allows to produce entirely human antibodies or to select a format different from natural antibodies. On the contrary, antibodies produced by the classical hybridoma technology described by Milstein *et al.*, can be only from mouse or rat and have the typical Y shaped format of four-chain antibodies. The four chains, identical pair-wise, comprise a heavy and a light chain, each consisting of a constant and variable region, as described by Rathburn, G. *et al.* (1989) in [[<<]]Immunoglobulin genes[>>]], Academic Press, New York.

[0044] According to a preferred embodiment, the anti-C5 recombinant antibody of the invention is characterised by the fact of recognising an epitope on the alpha chain of the

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C5 component, which comprises the cleavage region of C5 convertase. The binding specificity of the antibody of the invention for the epitope comprising the cleavage site for C5 convertase, which is positioned between glycine 733 and arginine 734 of human C5 according to the SwissProt Data Base numbering for human C5 (SEQ ID P01031), can be verified *in vitro*. For instance, it can be verified by means of an ELISA competition assay on C5 that makes use of a synthetic peptide, as for example the peptide KDMQLGR↓LHMKTLTPVSK (SEQ ID NO:15) (where the arrow indicates the proteolytic cleavage site), corresponding to the region 727-744 of the human mature protein. According to this aspect, the antibody is preferably characterised by the ability of recognising a region with at least 80%, preferably at least 90% 95% homology to the peptide KDMQLGR↓LHMKTLTPVSK (corresponding to the SEQ ID NO:15). More preferably it recognises an epitope of at least 6-10 amino acids composed of 1-5 amino acids upstream and 1-5 amino acids downstream the peptide bond cleaved by the enzyme C5 convertase, preferably the epitope is LGRLHM (SEQ ID NO:37). The region surrounding the cleavage site is highly conserved across several mammalian species, therefore the antibody of the invention recognises with very similar binding efficiency the C5 molecule of rat, mouse, rabbit etc. Moreover the antibody has in each animal species the same effect to block the conversion of activated C5 into its active fragments C5a+C5b.

[0045] The recombinant antibody of the invention is preferably in a single chain form (scFv), even more preferably it corresponds to SEQ ID NO:6, and comprises the variable region of the light chain covalently joined to the variable region of the heavy chain, either directly or via an amino acid sequence termed linker. Herein by scFv it is meant a single polypeptide chain antibody, composed of the variable region of the light chain joined to the variable region of the heavy chain either directly or via synthetic linker. Linkers composed of non-natural amino acid sequences (synthetic) are known in the art and are described for instance in (1999): Combinatorial Chemistry and Technology: Principles, Methods, and application, Marcel Dekker Inc, NY USA. The synthetic linker is preferably the nucleotide sequence SEQ ID NO:13 of the Sequence Listing.

[0046] In the scFv antibody of the invention, VH and VL chains are preferably in the order VL-VH from the N- to the C-terminus of the polypeptide chain. This format, in which the N-terminal consists of VL chain, confers greater hydrophilicity to the whole protein expressed as such and to fusion proteins comprising both VL and VH regions.



Furthermore it makes possible the upstream or downstream insertion of peptide sequences termed "tag" or "flag", which do not alter the binding characteristics but are used for instance to facilitate the immunological detection of the antibody, or its production or purification. For the purpose of the present invention, the antibody may also consist of the format (N-C terminus) VH-VL, or it may contain only one of the two variable chains, preferably the VH chain corresponding to SEQ ID NO:4, also in association with different VL chains, also independently of their specificity, as for instance selectable through interaction of the VH chain corresponding to SEQ ID NO:4 with "collections of molecular repertoires".

[0047] In the antibody of the invention, the VL chain has a sequence preferably corresponding to SEQ ID NO:12 that could be covalently linked to a VH chain which preferably corresponds to SEQ ID NO:4.

[0048] In the scFv antibody, preferably at least the VH chain has the above indicated anti-C5 specificity and preferably corresponds to SEQ ID NO:4 of the Sequence Listing or to the isotypic variants or conservative mutations of this sequence. Therefore, according to this aspect, the invention comprises all polypeptides comprising a region having at least 95% homology, preferably 98% or 99% homology with the amino acid sequence of the VH region, preferably VH3 corresponding to SEQ ID NO:4. A particularly preferred embodiment of this scFv is represented by the antibody having amino acid sequence corresponding to SEQ ID NO:6, which corresponds to sequence 4 and 2 joined by a linker peptide to a sequence corresponding to SEQ ID NO:14. In accordance with a particularly preferred embodiment the scFv antibody corresponding to the SEQ ID NO:6, has an equilibrium constant for the antigen higher than  $1 \times 10^7$ , preferably higher than  $1 \times 10^8$ .

[0049] In a preferred embodiment, the nucleotide sequence of scFv antibody is used to engineer expression cassettes for recombinant antibodies comprising the constant region of immunoglobulin heavy chains, preferably IgG, even more preferably of human, mouse or rat origin. Even more preferably these constructs comprise CH2 and CH3 regions either individually or in association. The expression cassettes made according to this procedure are cloned in suitable expression vectors which are used for transfection of eukaryotic cells, preferably of mammalian origin, as for instance HEK293, CHO, COS-1 BHK, myeloma cells or other cells suitable for expression of these protein products. According to a particularly preferred embodiment, the scFv antibody corresponding to

SEQ ID NO:5 is produced in recombinant form with rat CH2 and CH3 sequences. In this form, the recombinant antibody dimerizes and a dimeric scFv TSA22-12 represents a particularly preferred embodiment of the invention.

[0050] Anyway are enclosed in this scope of the present invention the amino-acid sequences obtained by mutation of the sequences contained in the annexed Sequence Listing, as long as these ~~mutation~~ mutations do not alter the described anti-C5 antibody specificity. The mutation can be "conservative", when it is based on an amino-acid with similar structural or chemical characteristics with respect to polarity, charge, solubility, hydrophobicity, hydrophilicity or it is based on the ~~amphipatie~~ amphipathic nature of the amino-acid residues involved. For instance groups of amino acids sharing similar characteristics of polarity are composed by non-polar (hydrophobic) aa which include alanine, leucine, isoleucine, valine, proline, phenylalanine, tryptophan and ~~metionine~~ methionine; non-polar or neutral amino acids that include: glycine, serine, threonine, cysteine, tyrosine, asparagine and glutamine; positively charged (basic) amino acids that include: arginine, ~~lysina~~ lysine and histidine; and the group of negatively charged (acidic) amino acids that comprises: aspartic acid and glutamic acid. Mutations also can be ~~also~~ produced randomly, for instance using DNA polymerases known to be "error prone". Therefore, according to a further aspect, this invention comprises recombinant antibodies generated by mutagenesis of nucleotide sequences SEQ ID NO:3 and 5 corresponding to sequences coding the VH region and for antibody in the scFv form. In accordance with this aspect, the invention therefore includes a procedure to generate antibodies with specificity for the C5 component of activated complement which may have or not have the ability to block cleavage of C5 alpha in its biologically active components. This procedure essentially includes the use of ~~anyone~~ any one of the sequences ~~IDN4 or IDN6~~ SEQ ID NO:4 or SEQ ID NO:6 or preferably the random or site directed mutagenesis of the nucleotide sequences encoding for SEQ ID NO:4 and NO:6. Therefore this procedure preferably includes mutagenesis of the nucleotide sequences ~~IDN3 and IDN5~~ SEQ ID NO:3 and SEQ ID NO:5.

[0051] Within the preferred format of the antibody, consisting of variable regions of antibody light or heavy chain fused in a single scFv chain via a protein linker, the light chain is more preferably the lambda chain, and in particular the V $\lambda$ 3/V2-14 chain, or the kappa chain, preferably the V $\kappa$ 4/DPK24. The heavy chain is the VH3 chain, in particular

the VH3/V-48, as defined in the ~~data base at the site: <http://www.mrc-cpe.cam.ac.uk/mt-doc/restricted/ok.html>~~ (Vbase index[[]]). According to this aspect the invention comprises all the antibodies derived by mutagenesis of the nucleotide sequence coding the VH chain or the scFv of the invention. These antibodies are characterized by the fact that they retain specificity for the C5 component of the complement system and of inhibiting cleavage of the C5 alpha chain, also termed activated C5, into C5a and C5b fragments.

[0052] It is known to the skilled person that the antigen binding specificity of an antibody is mainly determined by the CDR regions (Complementarity Determining Region) which are defined as hyper-variable regions of the antibody. Three hyper-variable regions for each variable region exist in both the heavy and the light chain. However, not unanimously accepted are the precise boundaries of the less variable or "framework" regions within which the CDR are comprised. Indeed two different classifications exist. The first is based on "sequence variability" (Kabat *et al.*), while the second is based on "structural variability" (Chothia *et al.*). However, because the antigen binding specificity is mainly due to the CDR regions, it has been possible, by using DNA recombinant techniques, to engineer chimeric antibodies that exploit the binding specificity of murine CDR mounted on the framework regions of human antibodies. The specificity of such antibodies turns out to be the same as for the murine antibody. The present invention is composed of amino acid and nucleotide sequences of the 3 CDR regions of the variable part of the light chain and of the 3 CDR regions of the variable part of the heavy chains (SEQ ID NO:7, 8, 9 respectively). Therefore are included in the range of the particular embodiment of the present invention all antibodies generated by "grafting" the CDR regions or at least the third CDR, corresponding to the SEQ ID NO:9, in other antibody support structure or in antibody-like support structures. Examples of the latter are "minibodies" in which the CDR of the invention are three-dimensionally positioned in a way to maintain C5 binding specificity.

[0053] In agreement with this aspect, the present invention comprises in the essence, whichever recombinant human antibody able to recognise the epitope comprising the cleavage region of C5 convertase on activated factor C5. The recombinant human antibody is preferably characterised by the fact that it comprises as CDR regions at least three of the amino acid sequences identified in the sequence listing, like: SEQ ID NO:7, SEQ ID NO:8, ~~seq~~ SEQ ID NO:9 or their conservative mutations.

[0054] Moreover the invention includes chimeric proteins comprising at least one of the polypeptides corresponding to the SEQ ID NO:2, 4, or 6 or those, obtainable by means of genetic engineering techniques, carrying conservative or non-conservative mutations and at least 95%, more preferably 98% or even 99% homologous to the original sequences. Therefore the invention extends to polypeptides comprising at least one of the antibody-specific amino acid sequences defined as SEQ ID NO:2, 4, 6, 8, 10, 12, also when those are prepared in a form that differs from the canonical or natural form of antibodies. Also comprised in the present invention are embodiments of chimeric immunoglobulin comprising at least one of the amino acid sequences identified as ~~IDN2~~ SEQ ID NO:2, 4 or 6 or functional domains derived from such sequences in combination with the amino acid sequence of Ig (immunoglobulin) heavy chain constant regions or subdomains of these regions (i.e. CH<sub>2</sub> or CH<sub>3</sub> domains) derived for example from amino acid (aa) sequences known in the database (i.e. human Ig A heavy chain gene of 00220, human Ig G heavy chain gene AF 237583, ~~mus~~ Mus musculus L27437 Ig gamma heavy chain, ~~Rattus Norvegicus~~ norvegicus heavy chain region M28671). Preferably the antibody is dimeric. The invention also comprises sequences selected among ~~IDN~~ SEQ ID NO:2, 4 or 6, when they carry mutations aa substitution or deletions which do not alter the binding specificity of the antibody of the invention.

[0055] The invention obviously extends to the amino acid sequences of the Sequence Listing also when they comprise additional peptides positioned at the C or N-terminus, as for instance the "tag" or "flag" sequences which are useful for purification or immunological recognition of the recombinant antibody in its various forms or when they carry deletions at the C- or N-terminus, but which do not alter their binding specificity.

[0056] A particularly preferred type of "tag" sequence is the poly-histidine tail, coded by the expression vector used in the present invention, which is expressed at the C-terminal end of sequence ID NO:6 in order to facilitate affinity purification on a nickel column. Another sequence tag is the SV5 of SIV, which is added in order to facilitate immunological recognition.

[0057] A further aspect of the invention is represented by all the nucleotide sequences resulting from degeneracy of the genetic code, characterised by the fact that they code the scFv antibody with sequence ID NO:6, or the VH heavy chain corresponding to SEQ ID NO:4, or the light chain corresponding to SEQ ID NO:2, and the nucleotide sequences coding polypeptides having at least 95% homology preferably 98% or 99% homology

with the SEQ ID NO:6, the SEQ ID NO:4, the SEQ ID NO:2, preferably with SEQ ID NO:4, or coding for their conservative variants. Therefore the nucleotide sequences identified with SEQ ID NO:1, 3, 5 of the Sequence Listing, or nucleotide sequences comprising such sequences, represent a particularly preferred embodiment of the nucleotide sequences of the invention.

[0058] Also included in the present invention are all the nucleotide sequences obtained by means of "parsimonious mutagenesis" (Shier, R., *et al.*, 1996, Gene 169: 147) or by means of other methods of random or directed mutagenesis of nucleotide sequences of the present invention, in particular SEQ ID NO:1, 3, 5 (Marks, J. D., *et al.*, 1992, J. Biol. Chem. 267:16007) performed in order to improve some of properties of antibodies, as for instance the affinity, while maintaining binding specificity for the C5 cleavage site. Moreover the present invention includes all scFv antibodies in which the sequence coding the VH region, corresponding to SEQ ID NO:3, is maintained constant, while the sequence coding the VL region of antibody TS-A12/22, corresponding to SEQ ID NO:1, is replaced by "chain shuffling", for example using collections ("libraries") of VL human regions.

[0059] The nucleotide sequences object of the present invention are cloned in vectors suitable for their amplification, further mutagenesis or modification or expression. Therefore, the vectors containing at least one of the nucleotide sequences ~~DN~~ corresponding to SEQ ID NO:1, 3, 5, 7, 9, 11 as in the sequence listing represent a further aspect of the invention. These are preferably used for preparation of recombinant antibodies or of chimeric proteins in a suitable host and following methods known in the art.

[0060] In accordance to a preferred embodiment of the present invention, the recombinant antibodies are preferably cloned and expressed in prokaryotic hosts: particularly preferred is *E. coli*, but other prokaryotic hosts can also be used, such as *B. subtilis*, *P. pastoris*, *K. Lactis*, or eukaryotic cells of plant [[o]] or animal origin. Expression vectors containing such nucleotide sequences are optimised for expression in each of these hosts, by insertion of suitable regulatory regions, promoters, transcriptional terminators or activators, or replication origin. A particularly preferred expression vector according to the present invention is represented by a periplasmic expression vector for *E. coli*, in particular the vector pDAN5 (Sblattero, D. and Bradbury A., 2000, Nat. Biotechnol. 18:75).

- [0061] The antibody or the chimeric proteins having the specificity described in the present invention inhibit C5 conversion to its biologically active products. In particular, by blocking C5b formation they block formation of the terminal complex C (TCC) that leads to formation of the MAC (Membrane Attack Complex) which is capable of determining massive cellular lysis and significant tissue damage. Moreover, by inhibiting C5a formation they also inhibit the chemiotactic activity of C5a for Polymorphonuclear Leukocytes and monocytes, that upon stimulation produce either cytokines such as IL-1, IL-6, IL-8, or other important inflammatory mediators such as Serin-elastases, peroxidases, etc.
- [0062] The C5a chemotactic activity and the cytolytic activity of MAC, to formation of which C5b participates, are considered the main causes of induced tissue damage in several inflammatory diseases. For instance, elevated levels of C5a fragment and of TCC have been found in the synovial fluid of patients with rheumatoid arthritis or in the cerebrospinal fluid of patients with several diseases of the central nervous system.
- [0063] Therefore a further aspect of the invention relates to therapeutic use of recombinant anti-C5 antibodies of the invention, preferably human, carrying the ability of inhibiting the conversion of the C5 component to C5a and C5b, in one of the forms described in the invention: scFv, VH and/or VL alone or in combination with constant regions of Ig, preferably of human, rat or mouse origin, chimeric proteins or single variable regions and their conservative mutations, isotypic variants etc. This aspect also relates to therapeutic use of their preferred embodiments composed of the amino acid sequences SEQ ID NO:2, 4, 6 of the Sequence Listing.
- [0064] In accordance to the invention, the antibodies block conversion of C5 by the C5 convertase. This enzyme can be activated by the classical pathway initiated by the C1q complement component triggered by antigen-antibody complexes or of IgG or IgM aggregates, or by the alternative activation pathway initiated by natural substances such as lectins, bacteria or yeast cell walls, or some snake venoms or nephritic factors. Therefore it has been assessed whether antibodies or proteins of the invention selectively block one or the other of the two complement activation pathways. Based on in vitro experiments performed by hemolytic assay on sheep erythrocytes (SRBC: Sheep Red Blood Cells) or on rabbit erythrocytes (RBC), the antibodies and proteins according to the present invention inhibit both classical and alternative complement activation pathways. An advantage provided by the use of antibodies or proteins having specificity for the C5

component in accordance to the present invention is that the initial complement components remain available for other functions of the complement system such as opsonization and clearance of immuno-complexes. This therapeutic approach turns out to be advantageous over a potential block at the level of the C3 component that precedes the action of the C5 component. A block at the level of the C3 component would lead to a total block of the complement cascade and of its functions in opsonization and clearance of immunocomplexes.

[0065] Therefore, in a particularly preferred embodiment, the antibodies or the proteins of the invention, in one of the described embodiments or in those obviously derivable from them, are used for pharmaceutical preparations for treatment of diseases caused or accompanied by hyper-activation of the complement system. The invention extends the use of antibodies and proteins of the invention, and their coding nucleotide sequences, to the diagnostic field, in the area of diagnosis of disorders characterised or accompanied by uncontrolled activation of the complement system, in particular of the C5 component or of its biologically active fragments.

[0066] More preferably, polypeptides and antibodies of the invention are used for treatment or prevention of diseases caused or accompanied by cytotoxic and pro-inflammatory action of the terminal C complex (Terminal C Complex TCC), where in particular such diseases comprise chronic inflammation, and in particular rheumatoid arthritis, glomerulonephritis, multiple sclerosis, demyelinating peripheral neuropathies, atherosclerosis or some autoimmune disorders.

[0067] Moreover, experimental tests have demonstrated that anti-C5 polypeptides and antibodies of the invention are therapeutically useful in both treatment and prevention of acute inflammatory pathologies induced or accompanied by massive activation of the C5 component, which acts through the chemotactic activity of the C5a fragment, as well as through the TCC activity initiated by the C5b fragment. For instance, acute pathologies are represented by bacterial sepsis, tissue damage, for example damage of the myocardium, of the central nervous, damages due to transplantation or caused by ischaemia and re-perfusion after ischaemia.

[0068] Moreover, a further aspect of the invention concerns the therapeutic use of nucleotide sequences coding antibodies or proteins of the invention, or the vectors containing them. Those are preferably used in somatic gene therapy of diseases induced or accompanied by massive activation of the C5 component, by uncontrolled activation of

the complement system, by excess production of C5a and C5b fragments, by excess production of complement components C5 to C9, as in rheumatoid arthritis or in some autoimmune disorders. Being subjected to individual variability and general health status, it is not easy to quantify a higher than normal level of activation of the complement system and of conversion of the activated C5 component to its biologically active fragments. Therefore abnormal levels are pragmatically defined as those that are able to cause an acute or chronic pathological state.

[0069] *In vivo* and *in vitro* production of antibodies of the invention in transgenic animals, obtained by genetic manipulation of non-human mammals using at least one of the nucleotide sequences described in the present invention by methods known to the expert of the field, is also comprised within the scope of the present invention. This represents a useful application to the study of genetic diseases characterised by insufficient production of C5a and C5b or by hyperactivation of complement components from C5 to C9.

[0070] Antibodies and proteins of the invention and their coding nucleotide sequences can be prepared for therapeutic use in the form of pharmaceutical compounds in combination with suitable excipients and/or diluents preferably for parenteral administration.

[0071] Moreover, the antibodies of the invention allow the preparation of diagnostic, therapeutic or research kits, where in such kits comprise at least one of the antibodies or of variable chains described in the invention, corresponding to sequences SEQ ID NO:2, 4, 6, or their homologous variants or fragments generated for diagnosis or prognosis of diseases characterised by hyperactivation of the C5 component or their encoding DNA sequences. The nucleotide sequences of the invention corresponding to sequences SEQ ID NO:1, 3, 5 and their homologous sequences, are preferably used to prepare kit for transfection of eukaryotic cells.

[0072] The present invention also comprises the realization of a kit for selecting compounds that interfere or modulate the cleavage of the alpha chain of the C5 complement component in its biologically active fragments. Realization of such kit involves the use of the polypeptides of the invention, preferably the VH chain (SEQ ID NO:4) or the scFv chain (SEQ ID NO:6) and at least one of the following polypeptides: C5 complement component and its alpha chain, or a peptide comprising the cleavage site for C5 convertase, preferably corresponding to sequence SEQ ID NO:15. The compounds



can be identified, as an example, by means of a competitive assay detecting the inhibition of peptide-antibody binding using at least one of the sequences of the invention. The antibodies and polypeptides of the invention, independently from the fact that they originate from a human antibody library, are characterised by the ability to recognise the C5 complement component at the level of an epitope present in the alpha chain of the C5 component and comprising the cleavage region of C5 convertase. The binding specificity of the antibody of the invention for the epitope comprising the cleavage site for C5 convertase is situated between glycine 733 and arginine 734 in human C5, according to the SwissProt Data Base numbering (SEQ ID P01031). This epitope could be differently located in C5 of non-human mammalian species such as rat, mouse, rabbit; however it will be considered as having the same specificity, would it have the effect to block conversion of the respective C5 to C5a and C5b.

[0073] Therefore, according to a further aspect, the invention relates to the use of anti-C5 antibodies of the invention for setting up animal experimental models of diseases induced or accompanied by hyper-activation of the complement system and in particular of the C5 component.

[0074] In accordance with a further aspect, the invention comprises also the peptide of complement factor C5 pertaining to mammalian species, and preferably human, that comprises the cleavage site for C5 convertase. This peptide is preferably that comprising the region corresponding to amino acids 731-740 of the human mature protein. Even more preferably the peptide has sequence KDMQLGR↓LHMKTLTPVSK (SEQ ID NO:15), corresponding to amino acid sequence 727-744 of the human protein. The peptides according to this last aspect of the invention are used for preparation of medicaments, for example vaccines, or as immunogen to prepare antisera for prevention and treatment of pathological conditions involving uncontrolled activation of the C5 complement component, such as rheumatoid arthritis or some autoimmune disorders.

[0075] In accordance with this further aspect, the invention includes also the use of a peptide comprising the region corresponding to amino acid sequence 731-740 of the human mature protein, or of a peptide sharing at least 80% homology with such region, more preferably at least 90% or 95% or 98% homology including the corresponding regions of the C5 component of non-human mammals. Even more preferably, this aspect of the invention includes the use of a peptide having sequence KDMQLGR↓LHMKTLTPVSK (SEQ ID NO:15) (derived from the human protein) or of

a peptide having at least 80%, more preferably at least 90% or 95% or 98% homology to such peptide, together with or in alternative to anti-C5 recombinant antibodies, in particular those comprising the variable region of the VH heavy chain, corresponding to SEQ ID NO:4, or the scFV antibody, corresponding to SEQ ID NO:6, to be used for selection of drugs and antibodies, even recombinant, capable of inhibiting conversion of activated C5 factor to its biologically active fragments C5a and C5b.

## EXPERIMENTAL SECTION

### Materials.

- [0076] Antibody library. The antibody library used, having a complexity of  $7 \times 10^9$ , was derived from human non-immune (naive) peripheral lymphocytes. The construction of this library is described in Sheets, M. D., *et al.*, 1998, Proc. Natl. Acad. Sci. USA 95:6157.
- [0077] Bacteria. Phage amplification was in *E. coli* strain DH5aF' (*F'**endA1 hsdR17 (rK<sup>m</sup>) supE44 thi-1 recA1 gyrA (Naf) relA1 D (lacZYA-argF) U169 deoR (F80dlacD(lacZ)M15)*). For scFv fragment preparation was used *E. coli* strain HB2151 (*K12, ara (lac-pro), thi/F' proA<sup>+</sup>B<sup>+</sup>, lack<sup>+</sup>ZM15*).
- [0078] Purified proteins. Purified components C4 to C9 were purchased from Quidel (Saint Diego, CA) and the human recombinant C5a component was purchased from ~~Sigma-Aldrich~~ SIGMA-ALDRICH® S.r.l. (Milan, Italy). C5 alpha and beta subunits were obtained by incubating 50 µg of C5 diluted in 0.55 M TRIS-HCl pH 8.1 containing DTT (0.02 M) for 30 min at room temperature (RT), followed by treatment with iodoacetamide (0.12 M) for 1 hour at RT. Alpha and beta chains were purified by gel filtration on Superose 12 (Pharmacia Biotech, Milan, Italy) in Fast Protein Liquid Chromatography (FPLC) and purity was assessed by SDS-PAGE in non-reducing conditions.
- [0079] Sera. A serum lacking in the C5 complement component (C5D) was obtained from a patient with meningococcal infection. C5 levels were below detection and haemolytic activity was lacking in this serum, and was restored by addition of exogenous of C5. Human serum obtained from blood donors was used as a source of C5 factor.
- [0080] Preparation of the intermediate EAC1-3b for hemolytic assay.

[0081] Sheep erythrocytes (SBRC: Sheep red blood cells) were sensitised with sub-agglutinating amounts of rabbit IgM (EA). The EAC1-3b intermediate for hemolytic reaction was prepared by incubating antibody-sensitised erythrocytes (EA) with 1/10 diluted C5 depleted serum (C5D) in salt buffer containing glucose and Veronal (GVBS). Incubation was performed for 70 minutes at 37°C., followed by addition of suramine (Bayer, FRG) to block the degradation reaction, as described by Harrison, R. A., and P. J. Lachmann (Harrison, R. A., and P. J. Lachmann. 1986. Complement technology. In Handbook of Experimental Immunology. D. M. Weir, L. A. Herzemberg, C. Blackwell, and A. Herzemberg Leonore, eds. Blackwell Scientific Publ, London.

[0082] Antisera. Two anti-C5a monoclonal antibodies (Oppermann *et al.* Complement Inflamm., 1991, 8:13) and a goat anti-C5 antiserum (Quidel, Saint Diego, Calif. U.S.A.).

Example 1.

Amplification and selection of phage library.

[0083] Phages were obtained and amplified as described in Marks, J. D. et al., 1991, J. Mol. Biol. 222:581. The selection was performed in "immunotubes" (Nunc, Mascia Brunelli, MI, IT) coated with purified C5 protein. Coating of "immunotubes" was obtained by incubation with a C5 solution (10 µg/ml in PBS) overnight at 4°C. Phages were diluted in PBS containing 2% non-fat dry milk (MPBS) and incubated in immunotubes for 60 minutes at room temperature. After incubation, the immunotubes were washed 20 times with PBS containing 0.1% Tween 20 (PBST) and 20 times with PBS. The phage particles bound to immunotubes were eluted with 1 ml of *E. coli* bacterial culture at a density of 0.5 OD<sub>600</sub> for 30 minutes at 37°C. Ampicillin (75 µg/ml), helper phage and kanamycin (25 µg/ml) were then added and the culture was grown overnight.

[0084] After a second selection cycle on C5 coated immunotubes, eluted *E. coli* cells were amplified to extract phagemid DNA using methods known in the art. The extracted DNA was used as template for separate PCR amplifications of VH and VL regions, and subsequent assembly and cloning in pDAN5 vector (Sblattero, D., and Bradbury A., 2000, Nat Biotechnol. 18:75). The pDAN5 vector is a phagemid vector containing lox and His<sub>6</sub> regions and the recognition region for the p27 SV5 protein of SIV virus, characterised by the fact that VH and VL regions inserted in the vector are expressed in VL-VH order, with the light chain at the N-terminus. After transformation with the

Marked-Up Version

phagemid, *E. coli* cells were incubated with the helper phage and phage particles were used for a third selection cycle. After elution, clones were analysed for their ability to bind C5 according to what is described in Example 2.

Example 2.

Isolation of phage particles with binding specificity for the C5 antigen.

[0085] The phage particles obtained after three cycles of C5 "panning" in immunotubes (as described in Example 1), were used to infect *E. coli* cells grown on solid medium. Single bacterial colonies were transferred in 96-well plates and the resulting phages were further tested by ELISA for their ability to bind C5. The C5 antigen, at a concentration of 10 µg/ml in 0.1 M bicarbonate buffer pH 9.6, was bound to the plates by overnight incubation at 4°C. After saturation of plates with MPBS (PBS containing 2% non-fat dry milk), 50 µl of phage suspension were diluted with an identical volume of MPBS; a monoclonal antibody anti-pIII (M13 protein) conjugated to HRP (Pharmacia Biotech) was then added. Positive binding was revealed by addition of H<sub>2</sub>O<sub>2</sub> and 3,3',5,5'-thetramethylbenzidine diclorate (~~Sigma-Aldrich~~ SIGMA-ALDRICH®), as substrate and absorbance at 450 nm by spectrophotometric reading.

[0086] Positive clones by the ELISA assay were further selected on the basis of the difference of V region coding fragments. V regions were amplified using specific primers as described in Marks et al. (cited work), cleaved with BstNI and electrophoretically separated on 2% agarose gel. Twelve clones were isolated that proved to be different from each other based on their electrophoretic pattern.

Example 3.

Preparation of soluble single chain ScFv antibodies.

[0087] Phage clones obtained as described in Example 2 were used to infect the *E. coli* strain HB2151 to obtain expression of scFv fragments in soluble form. Bacteria grown until O.D. 0.5 in 2XYT medium, containing ampicillin, were induced with isopropil-β-tiogalattopiranoside and further grown for 5 hours. The periplasmic fraction containing scFv antibodies was prepared by incubation with B-PER reagent (Pierce, Celbio, MI, IT) for 20 minutes at RT, followed by centrifugation for 15 minutes at 27000xg. The supernatant was dialyzed against PBS and single chain antibodies containing the poly-

histidine tail at the C-terminus were purified by affinity chromatography on nickel Ni-NTA resin (~~Qiagen~~QIAGEN®, MI, IT).

[0088] The binding capacity of purified single-chain antibodies for factor C5 was verified by means of a solid-phase ELISA assay. This was analogous to that used for phage particles. Rather than the antibody directed at pIII of M13, the antibody used for detection was a monoclonal antibody against peptide SV5-tag expressed at the C-terminus of single chain antibodies.

[0089] The protocol for the ELISA assay was the following: wells of a 96 well microtiter plate were coated with antigen (purified C5, 250 ng) by overnight incubation at 4°C. in 0.1 M sodium bicarbonate buffer, pH 9.6 and then washed with PBS 0.1% Tween 20 (PBST). Residual binding sites were blocked with PBS containing 1% BSA for 1 hour at 37°C. Bacterial extracts or purified single chain scFv antibody (1 µg/ml) were then incubated and revealed with anti-SV5tag antibody (diluted 1/1000) followed by goat anti-mouse IgG antibody (diluted 1/1000) during 1 hour incubation at 37°C. The enzymatic reaction was developed with p-nitrophenylphosphate (~~Sigma—Aldrich~~SIGMA-ALDRICH®; 1 mg/ml) as the substrate in 0.1M glycine buffer pH 10.4 containing, 1 mM MgCl<sub>2</sub> and 1 mM ZnCl<sub>2</sub>, and adsorbance at 405 nm was read by the ELISA reader Titertek multiskan.

[0090] All purified scFv antibodies were found to be capable of binding factor C5 by the described ELISA assay.

#### Example 4.

Determination of the binding affinity of scFv TS-A12 antibody for factor C5 by Surface Plasmon Resonance (SPR).

[0091] The binding affinity of the Tsa-12 antibody, purified by means of FPLC on Superdex 75 (Pharmacia), for factor C5 was measured by means of BIACORE™ 2000 (a system that generates unique data on the interactions between proteins and other molecules). The microchip (CM5, Biacore) was prepared by direct conjugation of the C5 antigen with amines (20 µg/ml in 10 mM Sodium Acetate pH 4.5). The final level of immobilisation turned out to be approximately 1000 RU (Resonance Units). Association and dissociation of antibody molecules from the bio-chip were measured using an optical detection system (Surface Plasmon Resonance).

[0092] The analysis was carried out at 25°C., at a flow of 15 µl/min, using 4 different scFv concentrations in the range comprised between 100-300 nM, in PBS, 0.005% P20 (Biacore). The binding curves were interpolated 1:1 according to the model of Langmuir, using the dedicated software termed BIAevaluation (version 3.5) with correction for the mass transfer. Measurements performed on the equilibrium dissociation constant are reported in table 1.

Table 1. Rates of association and dissociation of scFV TS-A12 on purified C5 immobilized on chip.

TABLE 1			
Rates of association and dissociation of scFV TS-A12 on purified C5 immobilized on chip.			
clone	$k_{on} (10^5 s^{-1} M^{-1})$	$k_{off} (10^{-3} s^{-1})$	$K_D (10^{-9} M)^a$
TSA-12	1.3	0.026	200

<sup>a</sup>The equilibrium constant was calculated as  $K_D = k_{on} / k_{off}$

clone	$k_{on} (10^5 s^{-1} M^{-1})$	$k_{off} (10^{-3} s^{-1})$	$K_D (10^{-9} M)^a$
TSA-12	1.3	0.026	200

<sup>a</sup>The equilibrium constant was calculated as  $K_D = k_{on} / k_{off}$

[0093] As it is shown in table 1, the KD calculated for the TS-A12 antibody turns out to be of  $2 \times 10^{-7}$  M (sub-micromolar affinity), as expected for antibodies derived from collections (libraries) of non-immune antibodies.

Example 5.

Increased affinity of the TS-A12 antibody by means of "chain shuffling".

[0094] In order to increase the affinity, the TS-A12 antibody was subjected to substitution ("shuffling") of the VL light chains. For this purpose the phagemid DNA was cut with BssHII and SaII to excise the VL region. This region was substituted with all the repertoire of VL chains of a preimmune library (Sblattero, D., and Bradbury A., 2000, Nat Biotechnol. 18:75) that was prepared with same enzymes. The library was subjected to three cycles of selection on the antigen, as described in examples 1 and 2, until a series of antibodies specific for C5 was obtained. Among those is TS-A12/22 having

dissociation constant, as measured with BIACORE 2000 according to the method described in the previous example, of  $1.8 \times 10^{-8}$  M, therefore with an increment of molar affinity of approximately one order of magnitude.

Example 6.

Characterisation of the inhibition from the antibodies scFv antiC5 of the conversion of C5 to C5a.

[0095] The obtained anti-C5 scFv fragments were further characterised for their ability to inhibit the hemolytic activity of C5 or, in other words, to block conversion of the C5 component to C5a. For this purpose, a small amount of purified C5 component was incubated, for 30 minutes at RT, with purified scFv anti-C5 antibodies, or with an unrelated scFv (anti-gliadin), or with VBS (Veronal Buffer Saline) as control. The mixture was then added to sheep erythrocytes sensitised with sub-agglutinating amounts of rabbit IgM (EA) (see Harrison, R, A., and P. J. Lachmann. 1986. Complement technology. In Handbook of Experimental Immunology. D. M. Weir, L. A. Herzenberg, C. Blackwell, and A. Herzenberg Leon ore, eds. Blackwell Scientific Publ, London) coated with components from C1 until C3b (EAC1-3b) that allow to reveal C5 activation through the classical pathway. The erythrocyte suspension was re-suspended in C5 depleted serum (C5D) and incubated for 30 minutes at 37°C. At the end of this procedure, cell lysis was measured as percentage of the control of total lysis in distilled H<sub>2</sub>O (see figure 1, panel B). The inhibition of C5a and TCC production by the scFv TS-A12 and TS-A12/22 was measured by means of ELISA using the monoclonal antibody 17/5 as the capture antibody and antibody G25/2 as detection antibody according to what has been described in Opperman *et al.*, 1991, Complement Inflamm. 8:13. The presence of TCC was measured using antibody aE11 as the capture antibody and a biotinylated anti-C5 antibody (~~Sigma—Aldrich~~SIGMA-ALDRICH®) followed by alkaline phosphatase-conjugated streptavidin, as described by Tedesco *et al.* (1997, J Exp. Med. 185:1619).

[0096] The results of the test are presented in Figure 1, where it is shown that antibodies TS-A12 and TS-A12/22 inhibit almost completely formation of C5a (Fig. 1A) (classical pathway) and of TCC (Fig. 1B) whereas the other isolated scFv are effective only partially or to a limited extent. The presence of VBS or of an unrelated scFv in the reaction mixture did not show, as expected, any inhibitory effect.

Example 7.

Determination of the sequence of TS-A12/22 antibody.

- [0097] The VH and VL fragment of positive clones was compared with known antibody sequences published in the VBASE data bank (~~http://www.mrc-cpe.cam.ac.uk/int-doc/restricted/ok.html~~). The VH heavy chain of TS-A12/22 antibody was found to be derived from the VH3/V-48 chain and the light chain from V $\lambda$ 3/V2-14. The DNA sequence coding the scFV TS-A12/22 antibody is reported in the Sequence Listing as SEQ ID NO:5, and the derived amino acid sequence as SEQ ID NO:6.

Example 8.

Mapping of the recognition site of the TS-A12/22 antibody on the C5 molecule.

- [0098] It was first characterised, by means of the Western-blotting technique, whether the TS-A12/22 antibody recognises the alpha or beta of subunit of the C5 complement component prepared as described in Materials. Briefly the two subunits were electrophoresed in separate wells and transferred on nitrocellulose membranes. A solution containing Tris 50 mM pH 7.6, 0.5 M NaCl and 4% skimmed powder milk was used to block non-specific sites for 1 hour at 37°C. Membranes were revealed by incubation with a suitable dilution of the TS-A12/22 antibody for 1 hour at 37°C., followed by incubation with a secondary antibody labeled with alkaline phosphatase or with streptavidin conjugated with alkaline phosphatase (~~Sigma-Aldrich~~ SIGMA-ALDRICH®). The enzymatic reaction was developed with blue tetrazolium and 5-bromo-4-chlorine-3-indolyl phosphate (~~Sigma-Aldrich~~ SIGMA-ALDRICH®, 0.30 mg/ml) diluted in 0.1 M Tris-HCl pH 9.5 containing 0.1 M NaCl and 5 mM MgCl<sub>2</sub>. Rainbow RPN 756 (~~Amersham~~ AMERSHAM™ Italy (a trademark of General Electric Healthcare Limited)) were used as molecular weight markers. As it is shown in figure 2, the TS-A12/22 antibody of the invention recognises the alpha sub-unit of the C5 factor, loaded in lane 1, while does not recognise the beta sub-unit, loaded in lane 2.
- [0099] Since the purified TS-A12/22 antibody also inhibited hemolytic activity due to inhibition of the conversion of C5 to C5a, as demonstrated in example 9, ~~it was then verified~~ the hypothesis that the antibody might recognise as binding site the cleavage site for C5 convertase was then verified.



[00100] In order to verify this hypothesis, a peptide of 18 amino acids was synthesised, with sequence: KDMQLGR↓LHMKTLTPVSK (P5A-18 also termed C5cs comprising SEQ ID NO:15). This peptide corresponds to region 727-744 of the mature protein and comprises the cleavage site of C5 convertase (indicated by the arrow) between glycine 733 and arginine 734 according to SwissProt numbering for human C5 (SEQ ID P01031). The peptide was used in a competitive ELISA assay on the C5 protein on solid phase. Before binding to the solid phase, the TS-A12/22 antibody was pre-incubated with the P5A-18 peptide, corresponding to amino acids 727-744 of the C5 component, or with an unrelated peptide of sequence GEEIQIGHIPREDVDYHLYP (SEQ ID NO:16 of sequence listing) corresponding to a fibronectin derived peptide termed CS5.

[0100] In figure 3 are shown the results that were obtained: the P5A-18 peptide inhibited binding of the TS-A12/22 antibody to C5, and this inhibition was dose-dependent, ranging from 45% to 90% for peptide concentrations of 200 ng and 800 ng/200 µl, respectively. This result confirms that the TS-A12/22 antibody recognises just this region on the activated factor C5. The concentration values correspond to a peptide  $K_i$  of 1 µM, that is not different from the  $K_D$  measured by SPR for the entire protein, according to what has been described in example 4.

[0101] As expected, both the unrelated peptide CS5 and the whole C5 protein resulted to be ineffective in inhibiting the binding of TS-A12/22 antibody to activated C5, even at the highest concentrations used, thus indicating that inhibition by peptide C5cs (P5a-18) was specific for the alpha chain of C5.

#### Example 9.

Functional characterisation of antibody TS-A12/22. Inhibition of hemolytic activity and TCC activation.

[0102] Having assessed the characteristics of the inhibition of the classical activation pathway of factor C5 by the TS-A12/22 antibody, it was then verified whether there was inhibition also of the alternative pathway of C5 activation, and at which level. The test was carried out using rabbit erythrocytes as the target cells, according to well-known methods. Briefly, increasing amounts of C5 were mixed with 600 ng of the scFv of the invention or with an unrelated scFv or with GVBS in which scFv antibodies have been solubilised, and then incubated for 15 minutes at room temperature. In order to estimate

the classical pathway of complement activation, each mixture was added to a 1% suspension of sheep erythrocytes sensitised with rabbit antibody and coated with complement component up to C3b, termed EAC1-3b. In order to estimate the alternative pathway of complement activation, each mixture was added to a 1% suspension of rabbit erythrocytes.

[0103] C5 depleted serum diluted 1/200 was added to each erythrocyte suspension. After incubation for 30 minutes at 37°C., the percentage of erythrocyte lysis was measured by comparison to a 100% value obtained by lysing erythrocytes with an equal volume of distilled of H<sub>2</sub>O and to a blank consisting of erythrocytes re-suspended in GBVS. Spectrophotometric reading was performed at 412 nm and the results are reported in figure 4: inhibition of EAC1-3b lysis through the classical pathway (A Panel); inhibition of lysis of rabbit erythrocytes through the alternative pathway (B Panel). The TS-A12/22 antibody inhibits rabbit erythrocyte lysis by inhibiting C5 conversion similarly through the classical pathway and the alternative pathway.

[0104] Since the amino acid sequence corresponding to the cleavage site of convertase on the C5 alpha chain is conserved in several animal species, it was furthermore evaluated, by hemolytic assay, the ability of TS-A12/22 antibody to inhibit conversion of C5 to C5a also in rabbit, mouse and rat sera. The TS-A12/22 antibody was capable of inhibiting the hemolytic activity present in the serum of all animal species tested, though with different efficiency. These results are reported in figure 5, showing that the efficiency of inhibition of rat serum was practically similar to that of human serum, whereas the efficiency was higher on rat or rabbit serum. It should be also considered that a higher amount of rabbit serum was necessary to induce a percentage of lysis comparable to that induced by human C5.

[0105] (The specificity of TS-A12/22 antibody was evaluated also on other components of the complement cascade, as for instance C3 and C4, which are structurally similar to C5, but cross-reactivity was not found).

Example 10.

*In vivo* use of TS-A12/22 antibody.

[0106] In order to test the effect of the TS-A12/22 antibody *in vivo*, the influx of PMN was measured in the rat joint injected with BSA, BSA and TS-A12/22 or BSA and

unrelated antibody. It was thus demonstrated that PMN chemotaxis, that is their number in the joint wash out liquid, was significantly reduced in presence of TS-A12/22 compared with rats treated with BSA or with BSA and unrelated antibody (Figure 6). Moreover the deposition of the C3 and C9 complement components was checked on a histological section of the joint of the back paw of treated rats, by immunofluorescence with specific antisera and fluorescein-conjugated secondary antibody (Figure 7). It was found that C3 deposition remained unchanged as result of the administration of BSA plus TS-A12/22 antibody or of unrelated antibody, but the deposition of C9 was strongly inhibited in presence of TS-A12/22. It was thus confirmed that the TS-A12/22 antibody inhibits the complement cascade at a step intermediate between C3 and C9 and therefore at the level of the conversion of C5 to C5a+C5b.

Example 11.

Dimerization of scFvTS-A12/22 antibody.

- [0107] The sequence of the TS-A12/22 antibody was modified by the addition of CH3 or CH2-CH3 domains to the C-terminal end and of an eukaryotic leader sequence to the N-terminal end.
- [0108] These modifications were aimed at:
- [0109] inducing scFv dimerization, by forming a structural complex, in order to increase the valence from one to two and to increase the stability of the antibody (hereafter defined "minibody"). Based on the different types of cloning, covalent bonds are not formed between subunits of the dimer in constructs comprising only CH3, while in those comprising CH2-CH3 domains are formed two ~~disulphide~~ disulfide bridges between cysteines of the CH2 hinge region of the two monomers;
- [0110] making possible the production of minibodies in mammalian cell cultures with increments of the yield and absence of bacterial contaminants at the end of extraction and purification procedures;
- [0111] creating the conditions for an in vivo analysis of the biological activity of the minibody in animal models, minimising the host immune response by adding CH3 and CH2-CH3 domains from the same species as the treated animal (mouse or rat).
- [0112] The above described modifications have been performed in two steps. First the scFv was cloned into plasmid vector pUT (Li E, *et al.* 1997. Protein Eng. 10:731-6)

conveniently modified in order to allow insertion of the leader sequence and of a human CH3 domain. The CH3 human domain was then replaced with a series of constructs of domains from other species, as reported below. Finally, a fragment of pUT vector comprising the minibody in various versions, was cloned in the commercial vector pcDNA3 (Invitrogen), and was tested for expression in cultured cell.

[0113] For this, the pUT vector containing an unrelated scFv was modified by replacing the recognition site for the restriction enzyme (RE) BspEI, located at the end of the VH chain, with the BssH2 site. The BspEI substitution was performed by inverse PCR done with the primers reported in Table 2 (references A and B).

[0114] The mouse CH3 sequence present in pUT vector was then replaced with an analogous human sequence amplified by use of reference primers 1 and 2. Primer 2 inserts in addition a SV5 tag sequence (recognised by mAB SV5), and the cloning sites SpeI, PvuI and EcoRI. cDNA from human B lymphocytes was used as template and insertion into pUT was performed by restriction with the RE BssHII and PvuI and subsequent ligation of vector and fragment.

[0115] As indicated in FIG. 8, Fc domains of human, mouse and rat antibodies were inserted into the pUT vector that had been modified as described in the previous point. The original sequences of CH2 and CH3 domains were obtained from <http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=Nucleotide>, an NIH nucleotide database using accession numbers:

*Homo sapiens* J00220 (locus: IgA1 heavy chain gene)

*Homo sapiens* AF237583 (locus: IgG1 heavy chain gene)

*Mus musculus*: L27437 (locus: Immunoglobulin gamma heavy chain)

*Rattus norvegicus* M28671; (locus: RATIGG2B).

[0116] Primers reported in Tab. 2 and cDNA from B lymphocytes of the corresponding species were used for PCR cloning. The cloning in pUT was performed by BssHII and SpeI restriction and ligation after removal of the previous sequence (human CH3).

[0117] The scFv sequence was cloned into a series of pUT vectors containing Fc domains of different species described in the previous point, by means of PCR with a mix of universal oligonucleotides for amplification of known human scFv (see Sblattero D. and Bradbury A, Immunotechnology, 1998, 3:271-278, and reported in table 3), followed by digestion with ApaLI and BssHII restriction enzymes (RE).

[0118] Cloning in pcDNA vector of the constructs obtained in pUT was done by digestion with HindIII and EcoRI enzymes, selective recovery of the corresponding fragment and cloning in pcDNA3 that was cut with the same RE (see outline in FIG. 8).

TABLE 2 Primers used for amplification of the Indicated Fc regions (Ra = rat; Mo = mouse; Hu: human).

TABLE 2			
Primers used for amplification of the Indicated Fc regions (Ra = rat; Mo = mouse; Hu: human).			
	Name	Orient.	Sequence
A	PUT-ApaLI	sense	5'ATC CGA GTG CAC ACC TGT GGA GAG AAA GGC AAA G 3'
SEQ. ID No. 17			
B	PUT-BsshII	antisense	5'TCC TCA GCG CGC GGC TCT GGT GGC AGA CCG AAG G 3'
SEQ ID No. 18			
1	HuGCH3-s	sense	5'CAG GCG GCG GGC GGG CAG CCC CAG GAA CCA CAG 3'
SEQ. ID No. 19			
2	HuGCH3-a	antisense	5'A CGT CGA TCG CCT GCT GAA TTC TTA AGT ACT ATC CAG GCC CAG CAG TGG GTT TGG GAT TGG TTT GCC ACT AGT TTT ACC CGG GGA CAG GGA GAG
SEQ. ID No. 20			

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Marked-Up Version  
TABLE 2-continued

Primers used for amplification of the Indicated Fc regions (Ra = rat; Mo = mouse; Hu: human).			
Name	Orient.	Sequence	
3	HuGCH2-s	sense	5' AG GCG GCG CGC GAC AAA ACT CAC ACA TGC CCA CCG TGC CCA 3'
SEQ. ID No. 21			
4	HuA-CH2-s	sense	5'CAG GCG GCG CGC GTT CCC TCA ACT CCA CCT ACC
SEQ. ID No. 22			
5	HuA-CH3a	antisense	5'CC GCT ACT AGT TTT ACC CGC CAA GCG GTC GAT
SEQ. ID No. 23			
6	MoG-CH3-s	sense	5' CAG GCG GCG CGC GGC AGA CCG AAG GCT CCA C
SEQ. ID No. 24			
7	MoG-CH3-a	antisense	5'CC GCT AGT AGT TTT ACC AGG AGA GTG GGA GAG
SEQ. ID No. 25			
8	MoGCH2-s	sense	5'CAG GCG GCG CGC GGT TGT AAG CCT TGC ATA TGT ACA
SEQ. ID No. 26			
9	RaGCH3-s	sense	5'CAG GCG GCG CGC GGG CTA GTC AGA AAA CCA CAG
SEQ. ID No. 27			
10	RaGCH3-a	antisense	5'CC GCT ACT AGT TTT ACC CGG AGG COG GGA GAT G
SEQ. ID No. 28			
11	RaGCH2-s	sense	5' CAG GCG GCG CGC CAC AAA TGC CCT ACA TGC CCT
SEQ. ID No. 29			

Table 2. Primers used for amplification of the indicated Fc regions (Ra=rat; Mo=mouse; Hu: human).

	Name	Orient.	Sequence
A SEQ. ID No. 17	PUT-ApaII	sense	5'ATC CGA GTG CAC ACC TGT GGA GAG AAA GGC AAA G 3'
B SEQ. ID No. 18	PUT-BssHI	antisense	5'TCC TCA GCG CGC GGC TCT GGT GGC AGA CCG AAG G 3'
1 SEQ. ID No. 19	HuGCH3-s	sense	5'CAG GCG GCG CGC GGG CAG CCC CAG GAA CCA CAG 3'
2 SEQ. ID No. 20	HuGCH3-a	antisense	5'A CGT CGA TCG CCT GCT GAA TTC TTA AGT ACT ATC CAG GCC CAG CAG TGG GTT TGG GAT TGG TTT GCC ACT AGT TTT ACC CGG GGA CAG GGA GAG
3 SEQ. ID No. 21	HuGCH2-s	sense	5' AG GCG GCG CGC GAC AAA ACT CAC ACA TGC CCA CCG TGC CCA 3'
4 SEQ. ID No. 22	HuA-CH2-s	sense	5'CAG GCG GCG CGC GTT CCC TCA ACT CCA CCT ACC
5 SEQ. ID No. 23	HuA-CH3a	antisense	5'CC GCT ACT AGT TTT ACC CGC CAA GCG GTC GAT
6 SEQ. ID No. 24	MoG-CH3-s	sense	5'CAG GCG GCG CGC GGC AGA CCG AAG GCT CCA C

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	Name	Orient.	Sequence
7 SEQ. ID No. 25	MoG-CH3- a	antisense	5'CC GCT <b>ACT AGT</b> TTT ACC AGG AGA GTG GGA GAG
8 SEQ. ID No. 26	MoGCH2-s	sense	5'CAG GCG <b>GCG CGC</b> GGT TGT AAG CCT TGC ATA TGT ACA
9 SEQ. ID No. 27	RaGCH3-s	sense	5'CAG GCG <b>GCG CGC</b> GGG CTA GTC AGA AAA CCA CAG
10 SEQ. ID No. 28	RaGCH3-a	antisense	5'CC GCT <b>ACT AGT</b> TTT ACC CGG AGG CCG GGA GAT G
11 SEQ. ID No. 29	RaGCH2-s	sense	5' CAG GCG <b>GCG CGC</b> CAC AAA TGC CCT ACA TGC CCT



Marked-Up Version

TABLE 3. Universal Oligonucleotides mix for amplification of scFv of human origin

TABLE 3		
Universal Oligonucleotides mix for amplification of scFv of human origin		
Name	Orientation	Sequence
VL1 SEQ. ID No. 30	sense	caggt <u>gtg</u> <u>cac</u> tcg gac atc crg dtg acc cag tct
VL2 SEQ. ID No. 31	sense	caggt <u>gtg</u> <u>cac</u> tcg gat att gtg wtg acn cag wct
VL3 SEQ. ID No. 32	sense	caggt <u>gtg</u> <u>cac</u> tcg cag cct gtg ctg car yc
VL4 SEQ. ID No. 33	sense	caggt <u>gtg</u> <u>cac</u> tcg tcc tat gwg ctg acw cag cca

TABLE 3-continued		
Universal Oligonucleotides mix for amplification of scFv of human origin		
Name	Orientation	Sequence
JH1 SEQ. ID No. 34	antisense	gaccc <u>gcg</u> <u>cgc</u> gga gac rgt gac cag ggt
JH2 SEQ. ID No. 35	antisense	gaccc <u>gcg</u> <u>cgc</u> aga gac ggt gac crt kgt

Name	Orientation	Sequence
VL1 SEQ. ID No. 30	sense	caggt <u>gtg</u> <u>cac</u> tcg gac atc crg dtg acc cag tct
VL2 SEQ. ID No. 31	sense	caggt <u>gtg</u> <u>cac</u> tcg gat att gtg wtg acn cag wct
VL3 SEQ. ID No. 32	sense	caggt <u>gtg</u> <u>cac</u> tcg cag cct gtg ctg car yc
VL4 SEQ. ID No. 33	sense	caggt <u>gtg</u> <u>cac</u> tcg tcc tat gwg ctg acw cag cca
JH1 SEQ. ID No. 34	antisense	gaccc <u>gcg</u> <u>cgc</u> gga gac rgt gac cag ggt
JH2 SEQ. ID No. 35	antisense	gaccc <u>gcg</u> <u>cgc</u> aga gac ggt gac crt kgt

## Example 12

Production and validation of the TSA12/22-CH2-CH3 rat minibody.

- [0119] pcDNA plasmid carrying the construct for the TSA12/22 antibody, in the version containing CH2-CH3 domains, was used for in vitro transfection of the HEK 293 cell line. After treatment with DNA and lipofectin, cells were selected in presence of the antibiotic G418. After two weeks in culture, single cell clones were assayed for antibody production by detection of the activity in the supernatant. One clone was chosen and expanded for massive production of the TSA12/22-CH2-CH3 minibody. Purification of the minibody was carried out by chromatography.
- [0120] Purified TSA12/22 antibody in the version containing the rat CH2-CH3 domains (minibody TSA12/22 CH2CH3) was tested for its ability to inhibit the classical complement activation pathway in an in vitro test, according to the modalities already described in the previous examples. In the diagram of figure 9 it is reported the percentage of inhibition of lysis of rabbit erythrocytes sensitized with IgM, mediated by complement in presence of fixed concentrations of scFv TSA12/22, of an unrelated scFv, of GVBS buffered salt solution and of the minibody composed of scFv TSA22/12 and rat CH2-CH3 domains.
- [0121] The Tsa12/22-CH2-CH3 construct showed significantly better inhibitory activity than the corresponding scFv, as can be noticed in Fig. 9.
- [0122] *In vivo* activity tests in the rat joint space were also performed. Arthritis was induced at time t=0 by intra-articular injection of metyl-BSA (bovine serum albumin) after the animal had been previously immunized with metyl-BSA. Therapeutic treatments with the minibody were performed by intra-articular injection at t=0 and 6 days after induction of arthritis. Efficiency of treatment was measured as number of polymorphonuclear leukocytes present in the intra-articular wash out and as reduction of joint swelling, as can be noticed in figure 10 where it is reported the course of PMN (polymorphonuclear leukocytes) recruited to the rat joint space in response to BSA-induced inflammation. The lower percentage of cells in presence of TSA22/12 CH2CH3 minibody, at two time points considered, indicates a reduction of the inflammatory process. Figure 11 reports the inhibitory effect of the TSA22/12 CH2CH3 minibody on the extent of joint swelling caused by the inflammatory reaction. The measurements

performed after 20 days assessed a therapeutic effect of the minibody also in the long term, either when it was administered together with BSA or 6 days later.

## CONCLUSIONS

- [0123] ScFv antibodies, isolated as described in example\_1, were found to be able to ~~binding~~ bind to factor C5, as assessed by ELISA assay and as expected from the type of selection or "panning" of phage particles performed on C5. However not all ScFv antibodies were able to inhibit conversion of C5 to C5a + C5b, and therefore the biological functions following their activation. Because it binds in proximity of the C5 convertase cleavage site on the alpha chain of the activated C5 component and prevents production of C5a and C5b, the TSA12/22 antibody inhibits the chemotactic activity induced by the former and the hemolytic activity mediated by C5b through MAC formation. This inhibition operates downstream of the activation of the C3 component, therefore it is independent from the type of complement activation pathway utilised (classical or alternative).
- [0124] Moreover, the TSA12-22 antibody dimerized by means of rat CH2 and CH3 domains (minibody) turned out to be particularly active in the long term treatment.

### Abstract

The present invention refers to recombinant antibodies of human origin specific for the C5 component of the activated complement and characterised by the ability to inhibit the conversion of the C5 alpha chain to C5a and C5b. Moreover the present invention refers to the nucleotide sequences coding for such antibodies and to the therapeutic use of both polypeptide and nucleotide sequences, in particular for the therapy of diseases involving tissue damage deriving from uncontrolled activation of the complement system.

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